

## Chapter 1: Diagnosing Air Leakage

### 1.1 Air Leakage Diagnostics Policy

Blower door testing is required on all buildings before weatherization is started (“As-Is” test), and upon completion of all measures that effect building tightness (“Final” test). Use the pressurization method of blower door testing whenever indoor air quality hazards exist in the building. Follow air-sealing protocol to complete air-sealing measures on the building. Perform Zone Pressure Diagnostics Testing on buildings with an attached garage. Document the results of air-leakage diagnostic testing in the Diagnostic Workbook. Take corrective action when air-sealing activities have contributed to a safety hazard or an indoor air quality issue.

### 1.2 Diagnostic Overview

The testing described here will help to analyze the existing air barriers and decide whether and where air sealing is needed.

An air barrier forms the building’s **pressure boundary**, while the insulation forms the building’s **thermal boundary**. The location and condition of these barriers have a substantial effect on the insulation’s effectiveness. For optimal energy savings and minimal heat loss, align the two barriers adjacently, with the air barrier positioned between the conditioned space and the insulation.

#### 1.2.1 Air Leakage Effects

Controlling shell air leakage is a key to a successful weatherization job. Decisions made about sealing air leaks will affect a building throughout its lifetime. The following list highlights important ways air leakage effects buildings.

1. Air leakage can significantly reduce insulation R-value.
2. Air leakage can account for a significant percentage of a building’s heat loss.
3. Air leakage moves moisture into and out of the house, affecting the relative humidity.
4. The location and amount of air leakage can affect the draft on natural-draft combustion appliances or fireplaces.
5. Sometimes air leakage provides ventilation for exhausting pollutants and admitting fresh air. However, air leaks can bring pollutants into the home as easily as they can expel them.

Building height and location, weather, and mechanical equipment effect air leakage in buildings. Strong winds may create a positive pressure on one side of a building, and a negative pressure on the opposite side. A forced air distribution system, a chimney, or an exhaust fan may create a negative pressure in the building.

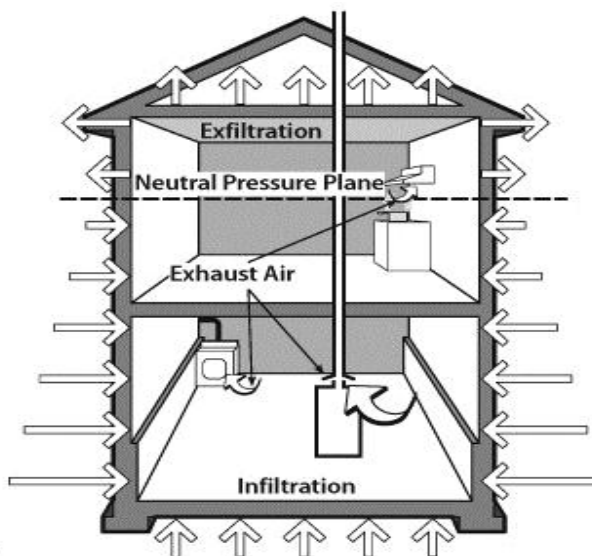
Often air moves through a building as if it were a chimney; air enters low in the building (infiltration) and exits at the top of the building (exfiltration). This is called the stack effect. The area between the air coming in at the bottom (infiltration) and the air leaving the building at the top (exfiltration) is called the neutral pressure plane. Not much air leakage comes in or goes out at the neutral pressure plane. As the building is tightened at the bottom, the neutral pressure plane moves up within the building. As the building is tightened at the top, the neutral pressure plane moves down. For the best results, seal at both the top and bottom of the building.

Air sealing may affect combustion appliance venting by changing house pressures or reducing the available supply of combustion air. After all weatherization measures are completed, worst-case draft testing must be done on all buildings that contain natural-draft combustion appliances or fireplaces. See *Worst-Case Draft Protocol in Chapter 5 – Section 5.6*.

### 1.2.2 Goals of Air-Leakage Testing

The primary goals of air-leakage testing are to determine the amount of air leakage and to complete pressure testing to determine locations of air leaks, while at the same time safeguarding indoor air quality.

A secondary goal of air-leakage testing is to decide where to locate the air barrier when an intermediate zone, like an attic or crawl space, provides a choice of air-barrier locations. The ceiling is usually the thermal boundary, for example, rather than the roof. However, at the foundation, the air barrier can be located at the first floor deck or at the foundation wall. Air-leakage testing helps establish the best place to locate the air barrier. Whenever possible, locate the air barrier to include plumbing and the air distribution system inside the pressure boundary. The air barrier can be located at the foundation wall or at the first floor deck, if

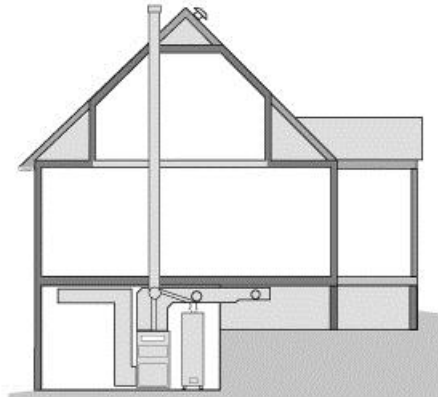


**Air leakage concepts:** When performing air sealing, it helps to understand the effects of exhaust appliances, the stack effect, and wind effect.

*Where is the primary air barrier:  
at the rafter or ceiling joist?*

*Are the intermediate  
zones connected?*

*Are the floor cavities  
connected to  
outdoors?*



*Do ducts supply  
heated air to the  
addition?*

*Is the half-basement inside or outside the air  
barrier? Is it heated?*

*Are the crawl space ducts inside or  
outside the air barrier?*

**Questions to ask and answer before air sealing:** Your answers help determine the most efficient and cost-effective location for the air barrier.

limited (or no) air distribution or plumbing is in the area. If plumbing is isolated outside the thermal boundary, take precautions to prevent pipes from freezing.

Testing is needed because there simply is no accurate prescriptive method for determining the severity and location of leaks. Depending on the complexity of a home, varying levels of testing may need to be performed to assess shell leakage.

It is most cost-effective to seal the large air leaks first. Chasing small leaks is not usually cost-effective. Refer to the “Air Sealing Protocol” worksheet in the Diagnostic Workbook for guidance about air-sealing protocol.

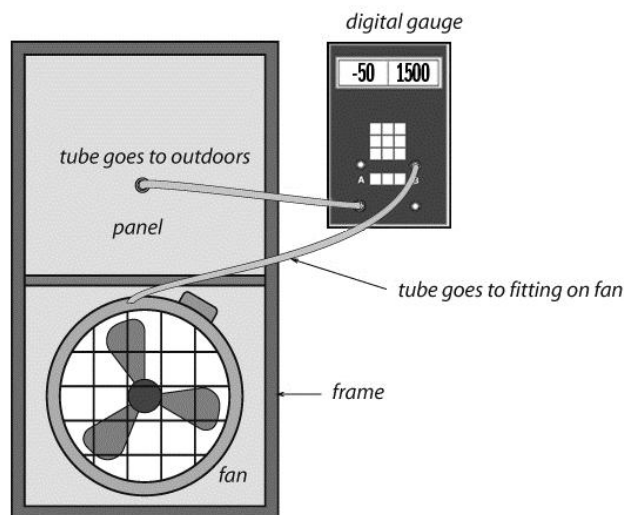
### **1.3 House Airtightness Testing**

The blower door measures a home’s leakage rate at a standard pressure difference of 50 Pascals. This leakage measurement can be used to compare air-leakage rates before and after air sealing. The blower door also allows the technician to test parts of the home’s air barrier to locate air leaks. Sometimes air leaks are obvious. More often, the leaks are hidden, and the technician uses the blower door to obtain clues about their location.

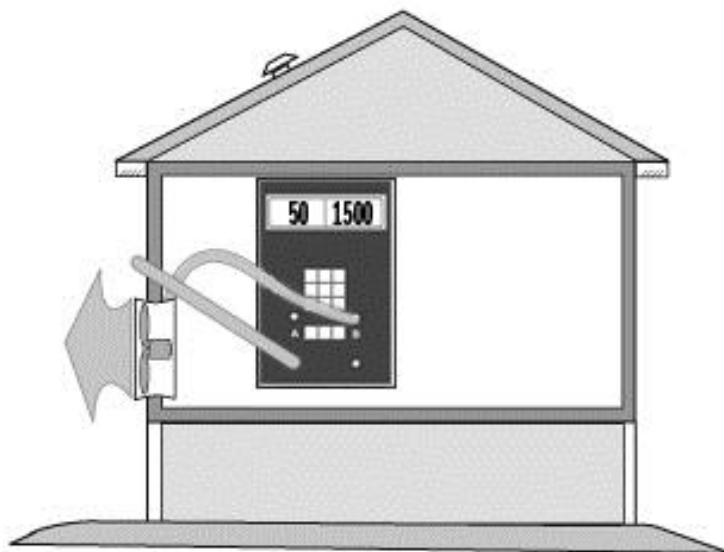
This section outlines the basics of blower door air-leakage measurement along with some techniques for gathering clues about the location of air leaks.

### 1.3.1 Blower Door Testing

The blower door creates a 50 Pascal pressure difference across the building shell and measures airflow in cubic feet per minute at 50 Pascals (in order to gauge the leakiness of homes). The blower door also creates pressure differences between rooms in the house and intermediate zones like attics, crawl spaces, and garages. These pressure differences can give clues about the location and size of a home's hidden air leaks.



**Blower door components:** Include the frame, panel, fan, and digital gauge.



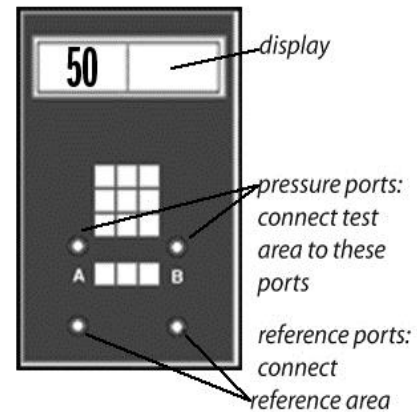
**Blower door test:** Air barriers are tested during a blower-door test, with the house at a pressure of 50 Pascals negative with reference to outdoors. This house has 1500 CFM<sub>50</sub> of air leakage. Further diagnostic tests can help determine where that leakage is coming from.

## Blower Door Terminology

Connecting the digital gauge's hoses correctly is essential for accurate testing. There is an accepted method for communicating correct hose connections that helps avoid confusion.

This method uses the phrase “*with reference to*” (WRT) to distinguish between the input zone and reference zone for a particular pressure measurement. The outdoors is the most commonly used reference zone for blower door testing. The reference zone is considered the zero point on the pressure scale.

For example, “*House WRT Outdoors = –50 Pascals*” means the house (Input) is 50 Pascals negative compared with the outdoors (Reference or zero-point). This pressure reading is called the house-to-outdoors pressure difference.



**Digital gauges:** Used to diagnose house and duct pressures quickly and accurately.

## Low-Flow Rings

During the blower door test, the airflow through the fan is calculated. This airflow is directly related to the surface area of the home's air leaks. For the blower door to measure airflow accurately, the air must be flowing at an adequate speed. Tighter buildings may not have enough air leakage to create an adequate airspeed (fan pressure) through the open fan. When the air speed is too low, the digital gauge will indicate insufficient airflow.

To increase fan pressure and airspeed, use the low-flow rings commonly provided with the blower door, to reduce the fan's opening and increase airflow through the fan. After attaching the low-flow rings, follow the manufacturer's instructions for selecting the proper setting on the digital gauge.

### 1.3.2 Preparing for a Blower Door Test

Preparing the house for a blower door test involves putting the house in “winter condition,” with door open to **all** conditioned areas (e.g., conditioned knee-wall spaces, and conditioned crawl spaces, etc.) “Winter condition,” entails closing all exterior doors and windows, as well as accesses to unconditioned spaces, and ensuring these stay shut for the duration of the test.

Try to anticipate problems the blower door test could cause. The blower door can cause flame rollout and back drafting in combustion appliances, as well as debris being drawn out of fireplaces.

Follow these steps when preparing for a blower door test:

1. Identify the location of the pressure boundary.
2. Open doors to all conditioned areas of the house.
3. Put the house in winter condition, with windows and exterior doors closed.
4. Survey pollutants that may pollute the air during a blower door test.
5. Turn off combustion appliances — but do not forget to turn them back on after completing the test. Leaving vehicle keys next to or on an appliance that has been turned off, prevents departure without turning the appliance back on.
6. Close all fireplace and stove dampers.

### **1.3.3 Blower Door Test Procedures**

Follow this general procedure when performing a blower door test:

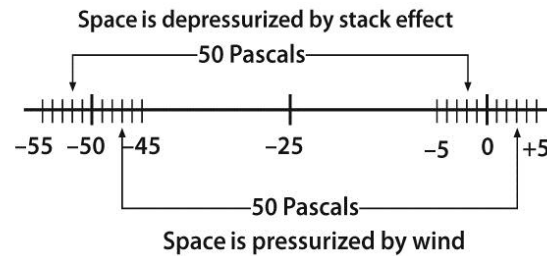
1. Install blower door frame, panel, and fan in an exterior doorway with a clear path to the outdoors and indoors. On windy days, try to place the fan parallel to the wind direction.
2. Follow manufacturer's instructions for fan orientation and digital gauge setup for either pressurization or depressurization. Use flow at 50 Pascals mode (PR/FL@50) on digital gauge to measure air leakage.

CAUTION: When the dwelling has an open-hearth fireplace, verify ashes will not be blown out of the hearth or run a pressurization test.

3. Connect a hose to the Reference tap of Channel A on the digital gauge, to measure House WRT Outdoors. Run this hose outdoors, at least 5 feet to the side of the fan, and ensure the hose opening is protected from the wind.
4. Connect a second hose to the Input tap of Channel B on the digital gauge. Run this hose to the pressure tap on the blower door fan.
5. FOR PRESSURIZATION TEST ONLY: Connect a third hose to the Reference tap of Channel B. Run this hose to the outdoors, next to the side of the fan.

6. To obtain accurate blower door measurements, readings must be adjusted for wind and stack effect. This adjustment is also referred to as “adjusting for the baseline.”

Attach all low-flow rings, so the fan opening is closed. Use the baseline feature of the digital gauge to adjust for the baseline. On windy days, allow the baseline function to record for at least 60 seconds.



7. Ensure children, pets, and any other potential obstructions are at a safe distance from the fan. Traffic should be eliminated in hallways and stairwells, if possible.
8. Remove low-flow rings as needed. Confirm the digital gauge's mode is still flow at 50 Pascals (PR/FL@50). Also, confirm the gauge's configuration setting matches the configuration of the low-flow rings.
9. FOR PRESSURIZATION TEST ONLY: Turn the blower door fan around, so the fan is moving air from outdoors to indoors. Do not use the fan switch to reverse direction. Physically turn the fan around.
10. Turn on the fan and increase its speed slowly until 50 Pascals of pressure difference between indoors and outdoors are reached. One or more low-flow rings may need to be re-attached, in order to display an accurate measurement on the digital gauge.
11. Document the CFM<sub>50</sub> from Channel B of the digital gauge in the Diagnostic Workbook. The workbook will adjust the blower door value for outdoor temperature.

### Blower Door Test Follow-up

1. Be sure to return the house to its original condition.
2. Inspect combustion appliance pilot lights to ensure blower door testing did not extinguish them.
3. Reset thermostats of heaters and water heaters that were turned down for testing.
4. Document any unusual conditions affecting the blower door test and location where the blower door was set up.

As a rule, 10 CFM<sub>50</sub> equal 1 square inch of direct air leakage into the conditioned space. For example, a blower door test of 1500 CFM<sub>50</sub> would indicate roughly 150 square inches of air bypass located on the dwelling's pressure boundaries.

## 1.4 Air Sealing and Indoor Air Quality

Air sealing affects the home's indoor-air quality by reducing the amount of natural ventilation. When natural ventilation is reduced below a certain level, mechanical exhaust ventilation is typically required to ensure that pollutants are exhausted to the outside and enough fresh air is brought into the building.

For instructions on how to calculate the whole-house ventilation requirement, refer to the "Instructions" page of the Diagnostic Workbook. Whenever possible, install the 100% mechanical ventilation rate.

See *Mechanical Ventilation in Chapter 5 – Section 5.9* for more information about ventilation requirements.

### 1.4.1. Non-Guideline Air Sealing

Air sealing work completed without using cost-effective guideline calculations is called Non-Guideline Air Sealing. The first blower door test (As-Is test) documents the overall leakiness of the building before weatherization work begins. It helps crews determine what sealing work needs to be completed before insulating the building. Non-Guideline Sealing is completed on the building prior to installing any other shell measures. It includes installing window glass where missing, sealing gross holes in the building envelope, sealing construction key junctures, and sealing all major attic bypasses. Install support for spans wider than 24 inches when they require air sealing or use material rated to span such distance under load (e.g., insulation load, wind load, etc.) The blower door and infrared camera can and should be used to locate air leaks. Penetrations will be sealed with a durable material with a minimum expected service life of 10 years. See *Zone Pressure Diagnostics (ZPD) in Chapter 1 – Section 1.5* for instructions regarding the use of zone-pressure testing to guide attic air-sealing.

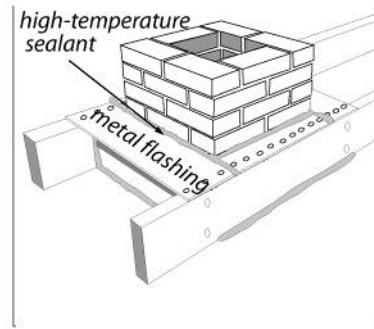
Common areas of Non-Guideline Air Sealing include, but are not limited to, the following:

#### Attics and Other Concealed Spaces

1. **Interior dropped soffits:** Cap the soffit with rigid material, and air-seal around the perimeter of the cap. If the soffit is located in a hard-to-access area, or along an exterior wall, consider dense-packing the soffit. When the soffit contains a non-IC-rated light fixture, obtain the homeowner's approval before replacing with an IC-rated or flush-mounted fixture.
2. **Around chimneys:** Use 26-gauge or heavier metal and high-temperature sealant to seal within 2 inches of the chimney.



3. **Balloon framing/open partition walls:** Cap the stud openings with rigid material and air-seal around the perimeter of the cap. Stuff the cavity with batts and seal with foam or dense-pack with insulation.
4. **Recessed lights:** For IC rated fixtures, seal the fixture. Use sealant or mastic to prepare for insulation. For non-IC rated fixtures, build a cover using non-combustible materials that do not allow for rapid heat transfer. Drywall may be used only if a three-inch clearance is maintained. Sheet metal is not an allowable material.
5. **Wall top-plates identified as leaking (exterior and interior walls):** Look for dirty insulation above top plates — this indicates air leakage. Pressurizing the home with the blower door will magnify smaller, hard-to-locate leaks. Use foam or caulk to seal leaky top plates.
6. **Electrical and other penetrations through wall top-plates:** Use one-part-foam or caulk.
7. **Ceiling penetrations:** These can include electrical fixtures, exhaust fans, soil stacks, dryer-exhaust pipes, and HVAC ductwork, etc. Seal with foam or caulk, as appropriate. Seal from the interior when possible, rather than from the attic.
8. **Key junctures:** Key junctures are framing voids and interstitial spaces where two or more building assemblies converge.
9. **Whole-house fan:** If the fan is operational, box around it and install a removable and airtight cover. The occupant should be able to remove the cover easily for future use.



**Sealing around chimneys:** Only non-combustible materials, like metal, may be used for sealing or damming around chimneys.

## Basement

1. **Sill box and sill-box penetrations:** Look for dirty sill-box insulation as evidence of air leakage. Using the blower door can magnify smaller leaks. Seal leaks with foam or caulk. If leaks are inaccessible from the interior, seal from the outside where the sill plate meets the foundation behind the siding.
2. **Foundation-block cores:** Cap the open cores using rigid material and air-seal around the perimeter of the cap. Treating block cores in this fashion seals leaks and limits convective looping.

3. **Bathtubs on exterior walls:** Install dense-packed insulation in the open space between the bathtub and the exterior wall, if feasible.
4. **Inactive chimneys and clean-outs:** Air-seal to prevent leakage and convective looping.
5. **Foundation penetrations:** Use foam or caulk to seal large penetrations identified in the foundation. If the foam will be exposed to sunlight, take precautions to protect the foam from deterioration. For gaps larger than ¼", use caulking, steel wool, or other pest-proof material to fill the penetration before sealing.

## Windows

1. **Missing window glass:** Install new window glass, or otherwise seal the opening, following lead- and asbestos-safe work practices. See *Window Repair and Replacement in Chapter 6 – Section 6.1.2* for information on window repairs and replacements. *Note: Air sealing of cracked window glass falls under Wisconsin Cost-Effective Guideline Air Sealing.*

## Doors

1. **Door repair:** Seal gaps between the stop and jamb with caulk. *Note: Sealing gaps between the door stop or jam falls under Wisconsin Cost-Effective Guideline Air Sealing.*
2. **Garage doors:** Weather-strip all doors connecting conditioned areas to an attached garage.

### 1.4.2 Guided Air Sealing and Wisconsin Cost-Effective Guideline Calculation

Guided air sealing covers air-sealing that occurs after the completion of non-guideline air sealing, shell measures, and the pre-blower door test. By definition, guided sealing covers the “minor” air-sealing measures: window and door weather-stripping, door sweeps, window air-sealing, and caulking around trim all fall under the heading of guided air sealing.

Wisconsin Cost-Effective Guidelines (WCEG) is a tool to guide workers as they air-seal by evaluating the cost-effectiveness of the air-sealing measures completed up to that point.

There is no maximum or minimum time limit for the first round of guided air sealing. Perform any air sealing to help to achieve the WCEG CFM<sub>50</sub>gl/Worker Hour. Refer to the instructions for the Diagnostic Workbook for guidance on using WCEG. Document all test results on the Diagnostic Workbook.

## 1.5 Zone Pressure Diagnostics

Zone pressure diagnostics (ZPD) help to quantify the air leakage from one “zone” to another. By using ZPD, workers can prioritize air-sealing in certain areas of the dwelling. ZPD may allow workers to save time working in zones whose air bypasses are insufficient to warrant extensive air sealing. Some common zones are attics, unconditioned knee-wall spaces, garages, and unconditioned crawl spaces.

ZPD tests calculate a **total path** of CFM<sub>50</sub> leaking from the outside through the zone into the conditioned space. When sealing “all major attic bypasses,” the guideline is the total path through all attics into the conditioned space should equal no more than 10 percent of the home’s cumulative air leakage. For example, a home with a final blower door test of 2200 CFM<sub>50</sub> should have a total path of no more than 220 CFM<sub>50</sub>.

When performing ZPD, use the estimated final blower door test, and not the in-progress blower door test, to calculate a zone’s leakiness. Document any unusual circumstances in the Comments section of the Blower Door Data worksheet within the Diagnostic Workbook. Perform ZPD testing when a building has an attached garage. Record the results of the test on the Garage ZPD worksheet within the Diagnostic Workbook.

Use ZPD to guide decisions about where to direct air-sealing efforts. ZPD can allow diagnosticians to:

1. Evaluate the air tightness of specific sections of a building’s pressure boundary — especially floors and ceilings.
2. Decide which of two possible air barriers to air seal — for example, at the floor versus at the foundation walls.
3. Estimate the air leakage in CFM through a particular air barrier.
4. Determine whether areas like floor cavities, porch roofs, and overhangs are conduits for air leakage.
5. Determine whether building cavities, intermediate zones, and ducts are connected by air leaks.

ZPD testing should be used whenever appropriate. Typically, that is when the dwelling has one or more of the following conditions:

1. Structural moisture problems related to moist air escaping into unheated zones.
2. Multiple zones where determining linkage between zones or setting air-sealing priorities is necessary.

- Unusually high blower door result with no indication as to where the infiltration originates Results of completed Zone Pressure Diagnostics should be documented on the required Zone Pressure Diagnostics Form within the Diagnostic Workbook.

**Table 1-1: Building Components and Their Air Performance**

Good Air Barriers ( $<2$ CFM <sub>50</sub> per 100 ft. <sup>2</sup> )	Fair Air Barriers (2-10 CFM <sub>50</sub> per 100 ft. <sup>2</sup> )	Poor Air Barriers (10-1000 CFM <sub>50</sub> per 100 ft. <sup>2</sup> )
$\frac{5}{8}$ " oriented strand board	15# perforated felt	$\frac{5}{8}$ " tongue-and-groove wood sheathing
$\frac{1}{2}$ " drywall	concrete block	6" fiberglass batt
4-mil air barrier paper	rubble masonry	1 $\frac{1}{2}$ " wet-spray cellulose
asphalt shingles and perforated felt over $\frac{1}{2}$ " plywood	$\frac{7}{16}$ " asphalt-coated fiberboard	wood siding over plank sheathing
$\frac{1}{8}$ " tempered hard-board	1" expanded polystyrene	wood shingles over plank sheathing
painted un-cracked lath and plaster	brick veneer	blown fibrous insulation

Measurements taken at 50 Pascal pressure.

Based on information from: "Air Permeance of Building Materials" by Canada Mortgage Housing Corporation, and estimates of comparable assemblies by the author.

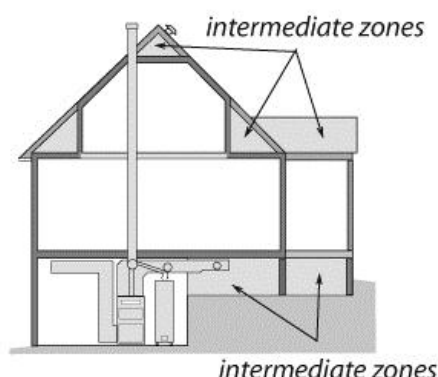
Although cellulose reduces air leakage when blown into walls, it is not considered an air-barrier material.

### Primary vs. Secondary Pressure Boundary

The **primary pressure boundary**, or air barrier, comprises those building-shell surfaces which contain the dwelling's conditioned air and which prevent air leakage. Ideally, the primary pressure boundary will be as continuous as possible, and it will be aligned with the building's thermal boundary.

The **secondary pressure boundary** comprises building surfaces that are outside the thermal boundary and which combine with the primary pressure boundaries to form intermediate zones.

**Intermediate zones** are spaces that are isolated outside of the home's thermal boundary, but which are sheltered within the home's exterior shell. Intermediate zones may include such unconditioned areas as basements, crawl spaces, attics, enclosed porches, and attached garages. Pre-weatherization, intermediate zones may be included either inside the home's primary pressure



boundary or outside it. After weatherization; however, these unconditioned zones should be isolated outside the home's primary pressure boundary.

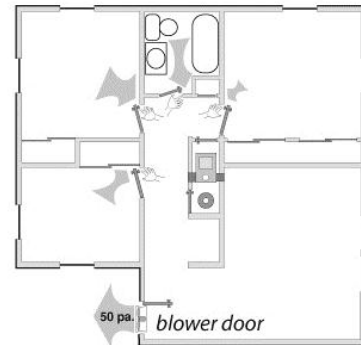
Intermediate zones have two potential pressure boundaries: one between the zone and house and one between the zone and outdoors. For example, an attic has two pressure boundaries: the ceiling and the roof deck. It is essential to determine which of the two is the primary pressure boundary.

After weatherization is complete, the most airtight boundary should be the primary pressure boundary and the least airtight should be the secondary pressure boundary. The primary pressure boundary should be adjacent to the insulation to ensure the insulation's effectiveness. The air barrier should be composed of materials that are continuous, sealed at seams, and relatively impermeable to airflow.

### 1.5.1 Simple Air-Leakage Tests

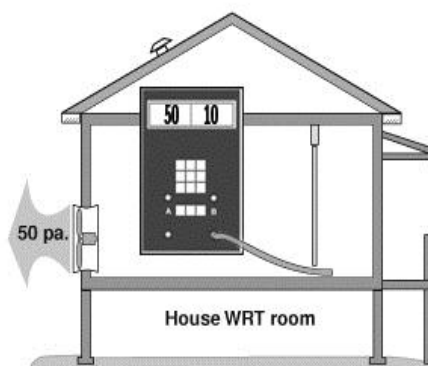
During a blower door test, valuable information about the relative leakiness of rooms or sections of the home can be identified. Following are five simple methods for locating air leaks.

1. **Feeling air leakage:** Feel for air movement. At the primary pressure boundary, air movement will be apparent during a **depressurization** test, but not during a pressurization test. Air leakage from a zone can be felt by closing an interior door so there is a small gap between the door and doorjamb. Feel the airflow along the length of that crack, and compare that airflow intensity with airflow from other rooms, using the same technique.
2. **Observing the building-shell surfaces:** With the blower door fan on, observe the building shell areas with an infrared camera or a good flashlight. To locate air leaks from intermediate zones, pressurize the home, and look for movement of loose-fill insulation, blowing dust, and moving cobwebs, etc. To locate air leaks from the interior, depressurize the home and look for moving cobwebs and blowing dust, etc. On the infrared camera, areas of high-contrast indicate the presence of air leakage.
3. **Observing smoke movement:** Pressurize the home, and use a smoke generator to detect areas of air leakage. This is the best method to diagnose primary pressure boundary air leakage during a **pressurization** test.



**Interior door test:** Feeling airflow with your hand at the crack of an interior door gives a rough indication of the air leakage coming from the outdoors through that room.

4. **Room-pressure difference:** Check the pressure difference between a closed room and the main body of a home. Larger pressure differences indicate more potential air leakage within the closed room, or perhaps a tight air barrier between the room and main body. A small pressure difference means little leakage to the outdoors through the room, or perhaps a leaky air barrier between the house and room.
5. **Room-airflow difference:** Measure the house CFM<sub>50</sub> with all interior doors open. Close the door to a single room and note the difference in the CFM<sub>50</sub> reading. The difference is the approximate leakage through that room.



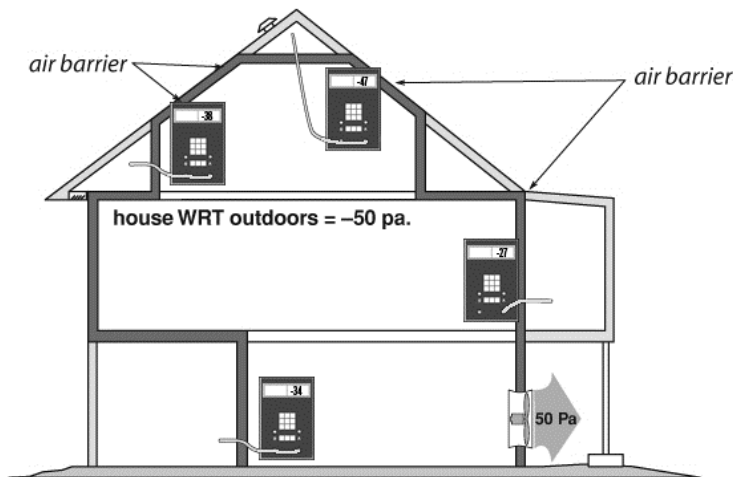
**Bedroom test:** This bedroom pressure difference may be caused by its leaky exterior walls or tight interior walls, separating it from the main body of the home. This test can determine whether or not a confined combustion zone is connected to other rooms.

Tests 1, 2, and 3 present good client-education opportunities. Feeling airflow or observing smoke are simple observations, but have helped identify many air leaks that could otherwise have remained hidden. When airflow within the home is restricted by closing a door, as in tests 4 and 5, it may take alternative indoor paths that reduce the accuracy of the test. Only good sense and experience can guide decisions about the applicability and usefulness of these simple tests.

### 1.5.2 Using a Digital Gauge to Test Pressure Boundaries

A digital gauge, used for blower door testing, also can measure pressures between the house and its intermediate zones during blower door tests.

The blower door, when used to create a house-to-outdoors pressure difference of 50 Pascals, also creates house-to-zone pressure of 0 to 50 Pascals in the home's intermediate zones. The amount of pressure differential depends on the relative leakiness of the zone's two pressure boundaries.



**Pressure-testing building zones:** Measuring the pressure difference across the assumed thermal boundary tells you whether the air barrier and insulation are aligned. If the digital gauge reads close to -50 Pascals, they are aligned, assuming the tested intermediate zones are well-connected to outdoors.

For example, in an attic with a fairly airtight ceiling and a well-ventilated roof, the attic is mostly outdoors if the house-to-zone pressure is 48 to 50 Pascals. The leakier the ceiling and the tighter the roof, the smaller the house-to-zone pressure differential will be. This principle holds true for other intermediate zones like crawl spaces, attached garages, and unheated basements

### **Pressure-Only Zone Pressure Diagnostics**

1. Find existing holes between the conditioned space and the intermediate zone. Or, with the customer's permission, drill a hole through the floor, wall, or ceiling into the zone.
2. Run a hose into the zone, and connect the hose to the Channel B Reference tap of the digital gauge.
3. Leave the Input tap of the digital gauge open to the indoors.
4. Turn the blower door on and create a 50-Pascal pressure difference between the House with reference to Outdoors (HwrtO).
5. Read the Channel B pressure differential. This is the House with reference to Zone (HwrtZ) pressure differential. As a rule, readings approaching 50 Pascals indicate the zone is less connected to the house compared to the connection to outdoors. Readings lower than 50 Pascals generally indicate the presence of air leaks along the primary pressure boundary. The lower the house to zone pressure, the greater the leakage will be.

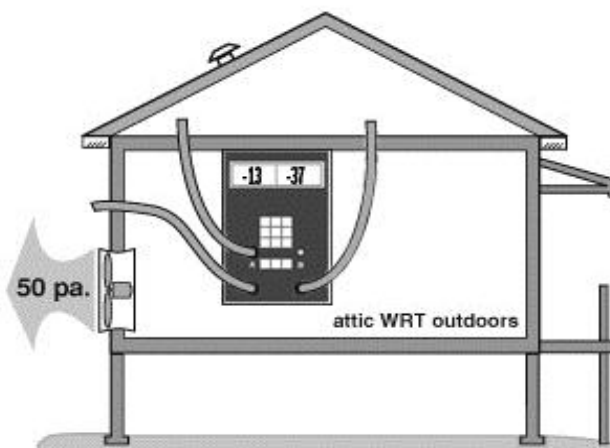
The main principle of series air leakage is a direct relationship between the measured pressure differentials and the ratio of the size of holes in the primary and secondary pressure boundaries.

This method allows the user to calculate the air-leakage surface area through one of the boundaries, if the air-leakage surface area through the other boundary is known or presumed.

For example, testing may indicate a HwrtZ pressure differential of 41 Pascals and a ZwrtO differential of 9 Pa, when the HwrtO pressure difference is 50 Pascals. Per Attic Bypass Relationships chart, if the secondary pressure boundary contained 9 square feet of ventilation, then this would indicate the presence of roughly 3 square feet of bypasses located along the primary pressure boundary.

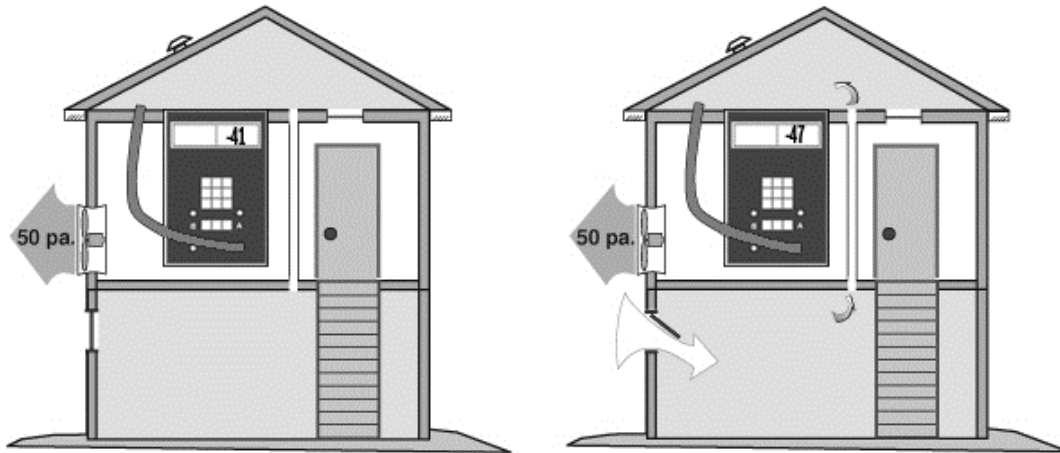
Attic Bypass Relationships		
Zone Pressures		Relative Size of Bypass Holes Compared to Roof Holes (e.g., ventilation)
ZwrtO	HwrtZ	HwrtZ
1	49	1/13
2	48	1/8
5	45	1/4
9	41	1/3
13	37	1/2
25	25	1
38	12	2

- If testing indicates the presence of substantial air leaks, find and seal the air barrier's leaks.



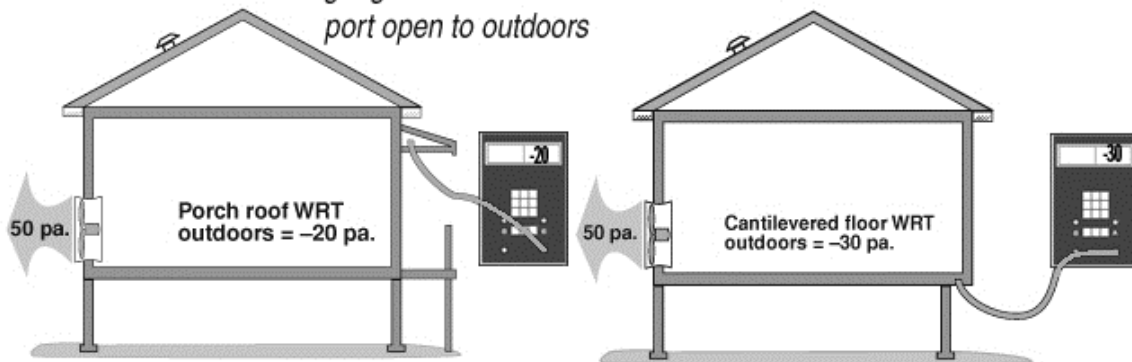
**Attic-to-outdoors pressure:** The left side of the gauge shows an Attic WRT outside pressure of -13 Pascals and the right side of the gauge shows a House WRT Attic pressure of -37 Pascals. The two readings add up to -50 Pascals to confirm House WRT Outside of 50 Pascals.





**Zone connectedness:** The attic measures closer to outdoors after the basement window is opened, indicating that the attic and basement are connected by a large bypass.

*These examples assume that the digital gauge is outdoors with the reference port open to outdoors*



**Porch roof test:** If the porch roof were outdoors, the digital gauge would read near 0 pascals. We hope that the porch roof is outdoors because it is outside the insulation. We find, however, that it is partially indoors, indicating that it may contain significant air leaks through the thermal boundary.

**Cantilevered floor test:** We hope to find the cantilevered floor to be indoors. A reading of -50 pascals would indicate that it is completely indoors. A reading less negative than -50 pascals is measured here, indicating that the floor cavity is partially connected to outdoors.

## Leak-Testing Building Cavities

Building cavities such as wall cavities, floor cavities between stories, and dropped soffits in kitchens and bathrooms can also be pressure-tested with a digital gauge to determine their connection to the outdoors.

## Testing Zone Connectedness

Sometimes it is useful to determine whether two intermediate zones are connected by an air passage like a large bypass. Determining whether two zones are connected can be completed by measuring the house-to-zone pressure during a blower door test and then later after opening the other zone to the outdoors. Opening an interior door leading into one of the zones and check for pressure changes in the other zone can also help determine connections.

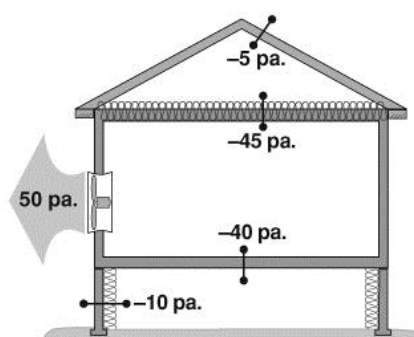
1. Turn on the blower door and establish a house-to-outside pressure differential of 50 Pascals.
2. Test and record the house-to-zone pressure differential of one of the zones.
3. Open a door, or create some other pathway, into the other zone.
4. Re-establish a house-to-outside pressure differential of 50 Pascals, as opening the pathway will change the overall house pressure.
5. Re-test the house-to-zone pressure differential in the first zone. If opening the pathway has caused the test result to change, then this is evidence of a connection between the two zones.

### 1.5.3 Locating the Pressure/Thermal Boundary

Where to air-seal and insulate are important retrofit decisions. Zone pressures are one of several factors used to determine where the thermal boundary should be located. When there are two choices of where to insulate and air-seal, zone pressures along with other considerations help decide where to locate the pressure and thermal boundaries.

For zone-leak-testing, the house-to-zone pressure is often used to determine which of the two pressure boundaries is tighter.

For example, a house-to-zone pressure differential of 26 to 50 Pascals means the primary pressure boundary is likely tighter than the secondary boundary. If the secondary boundary is quite airtight, achieving a 50-Pascal house-to-zone pressure differential is difficult.



**Pressure measurements and air-barrier location:** The air barrier and insulation are aligned at the ceiling as they should be. The crawl-space pressure measurements show that the floor is the air barrier and the insulation is misaligned—installed at the foundation wall. We could decide to close the crawl space vents and air-seal the crawl space. Then the insulation would be aligned with the air barrier.

However, if the roof is well ventilated, creating a nearly 50-Pascal differential is possible. If the roof is over-ventilated, creating a nearly 50-Pascal differential is easy.

By contrast, a house-to-zone pressure differential of zero to 25 Pascals means the secondary pressure boundary is tighter than the primary boundary. If the roof is well ventilated, then these readings indicate the ceiling has even more leakage surface area than the roof.

### **Floor vs. Crawl Space**

The floor shown here is tighter than the crawl-space foundation walls. If the crawl-space foundation walls are insulated, holes and vents in the foundation wall should be sealed until the pressure difference between the crawl space and outside is as close to 50 Pascals as possible—ideally more than 48 Pascals. A leaky foundation wall renders its insulation ineffective.

If the floor above the crawl space were insulated instead of the foundation walls in the previous example, then the thermal boundary would be the floor.

Often, it will make more sense to locate the thermal boundary at the crawl-space foundation walls, rather than at the floor. Locating at the foundation walls eliminates the concern about frozen pipes in the crawl space. In addition, treating the foundation walls usually requires less work and material than treating the floor. When the crawl space is adjacent to the basement, and the thermal boundary has been determined at the floor, remember the thermal boundary now also includes the wall separating the basement from the crawl space. Insulate and air-seal this wall appropriately.

**Table 1-2: Crawl Space: Where Should the Air Barrier Be?**

<b>Factors Favoring Foundation Wall</b>	<b>Factors Favoring Floor</b>
Ground moisture barrier and good perimeter drainage present or planned	Damp crawl space with little or no improvement offered by weatherization
Foundation walls test tighter than floor	Floor tests tighter than foundation walls
Furnace, ducts, and plumbing located in crawl space	No plumbing or heating located in crawl space
Foundation wall is insulated	Floor is insulated

**Table 1-3: Unoccupied Basement: Where Should the Air Barrier Be?**

Favors Foundation Wall	Favors Floor
Ground drainage and no existing moisture problems	Damp basement with no solution during weatherization
Interior stairway between house and basement	Floor air sealing and insulation is a reasonable option, considering access and obstacles
Ducts and furnace in basement	No furnace or ducts present
Foundation walls test tighter than the floor	Floor tests tighter than foundation walls
Basement may be occupied some day	Exterior entrance and stairway only
Laundry in basement	Rubble masonry foundation walls
Floor air sealing and insulation would be very difficult	Dirt floor or deteriorating concrete floor
Concrete floor	Badly cracked foundation walls

### Garage Boundary

For a tuck-under or attached garage, locate the thermal and pressure boundaries at the floor and walls that separate the garage from the living spaces. Ensure plumbing pipes in these floor and wall cavities are located on the interior (warm) side of the thermal and pressure boundaries to prevent frozen pipes.

For tuck-under garages, make sure to air-seal the floor-joint key juncture above the wall that separates the garage from the home. Use the Bag Method if necessary. See *Installing Attic Insulation in 1½ Story Homes (Finished Attics)* in Chapter 2 - Section 2.2.7 on for more information about the Bag Method.

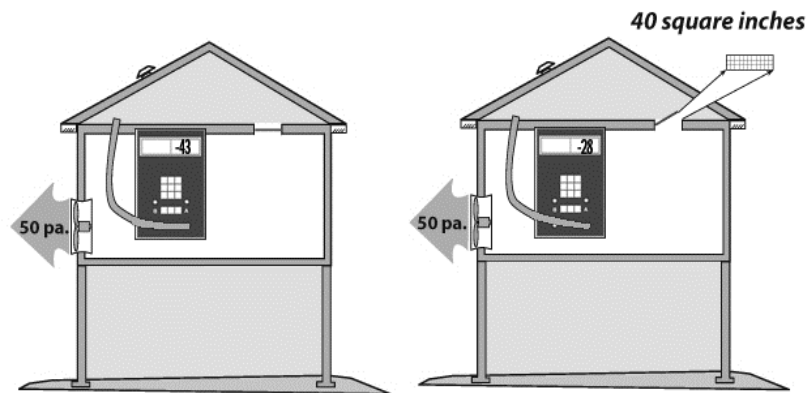
### Duct Location

Whenever feasible, locate the thermal and pressure boundaries to include ductwork. This is a better option than isolating the ducts outside the thermal boundary, because it reduces energy waste from duct leakage.

### 1.5.4 Add-a-Hole Zone-Leakage Measurement

The Add-a-Hole procedure estimates the actual airflow between the house and zone. Use the Add-a-Hole worksheet within the Diagnostic Workbook to perform the calculations described here. This procedure works for most intermediate zones that have an opening or access to the indoors.

The Add-a-Hole worksheet calculates Leakage Results based on user data inputs. The three Leakage Results calculations are:



**Add-a-hole test:** The first house-to-attic pressure is -43 pascals. This test works equally well with crawl spaces and attached garages.

**Add-a-hole test 2:** Opening a hole of approximately 40 square inches drops the second house-to-zone pressure by 15 pascals.

**Total path:** This number represents the amount of  $\text{CFM}_{50}$  passing through both pressure boundaries.

**House with reference to zone:** This number represents the amount of leakage between the house and zone.

**Zone with reference to outside:** This number represents the amount of leakage between the zone and outside.

The target total path leakage percentage for attics is 10 percent or less of the total blower door value. This number is calculated by the following equation:

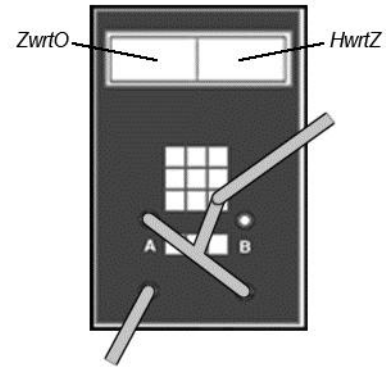
$$\text{Percentage} = \text{Total Path} \div \text{Whole-House CFM}_{50}$$

Before commencing the Add-a-Hole Zone-Leakage Test, confirm a “hole” can be opened between the house and the zone and/or between the zone and the outside. The hole might be an attic hatch, a door to the zone, or some other opening.

Follow these steps to complete the Add-a-Hole ZPD test:

1. Set up for a standard blower door test. Put the home in winter condition, turn off all combustion appliances, and keep interior doors stationary during testing.
2. Run a pressure hose to the outdoors. Run a second pressure hose into the zone, keeping the hose end away from roof vents and large bypasses. Both hoses will be connected to the digital pressure gauge later during the test. Ensure each hose is long enough to reach.
3. Turn on the pressure gauge and leave in PR/PR mode for all testing. *Do not use the Adjusted Baseline feature of the digital gauge when completing zone-pressure diagnostics.*
4. Connect a jumper tee to the Channel A Input tap and the Channel B Reference tap. Leave the jumper tap open to the indoors for the time being, with no hose connected. Connect the outdoor pressure hose to the Channel A Reference tap of the digital pressure gauge.
5. Open the Add-a-Hole worksheet in the Diagnostic Workbook. Select the Type of Test — depressurization or pressurization — to be conducted.
6. Connect the zone pressure hose to the jumper tee. Record the Zone with reference to Outside (ZwrtO) baseline from Channel A, and the House with reference to Zone (HwrtZ) baseline from Channel B.
7. Remove the zone pressure hose. Measure the House with reference to Outdoors (HwrtO) baseline pressure differential. Enter the result in the Diagnostic Workbook, as a positive or a negative number. The Workbook will then calculate the Adjusted Pressure — which becomes target pressure reading during the blower door test.
8. Start the bower door fan to create an HwrtO pressure difference and adjust to match the targeted pressure reading.

9. Reconnect the zone pressure hose to the jumper tee. Record the ZwrO reading from Channel A, in the Pressure with House at 50 Pascals line of the Add-a-Hole worksheet. Record the HwrtZ reading from Channel B, in the same line of the worksheet.
10. Turn off the blower door fan. Create a hole by opening the access between the zone and the house. The size of hole opened depends on the measured HwrtZ Pressure With House at 50 Pascals. A hole too large or too small may lead to incorrect results.
11. Repeat Steps 6-9. The HwrtZ pressure reading with the hole added between the house and zone should be between 6 and 20 Pascals lower than the HwrtZ reading from before the hole was added. If the HwrtZ reading is more than 20 Pascals different, reduce the size of the hole. If the HwrtZ reading is fewer than 6 Pascals different, increase the size of the hole. *If the size of the hole is changed, the baseline must be re-established (see Step 6).*
12. Determine the surface area of the final hole, in square inches. Be sure to account for the triangular spaces created on either side of the access hatch when the hatch is tilted open. Enter the dimensions of the opening so the Add-a-Hole worksheet calculates the Opening Size to match the hole's surface area.
13. When the HwrtZ reading from Channel B falls within the range of 6 to 20 Pascals difference, record it in the Pressure With House at 50 Pascals line of the Add-a-Hole worksheet, in the "Pressure Readings After Adding a Hole" section. Record the ZwrO reading from Channel A, in the same line of the worksheet.
14. The test is complete. Return the home to the pre-test conditions — and remember to turn combustion appliances back on.



Follow the warning indicators in the Add-a-Hole worksheet, if they appear.

### 1.5.5 Open-a-Door Zone-Leakage Measurement

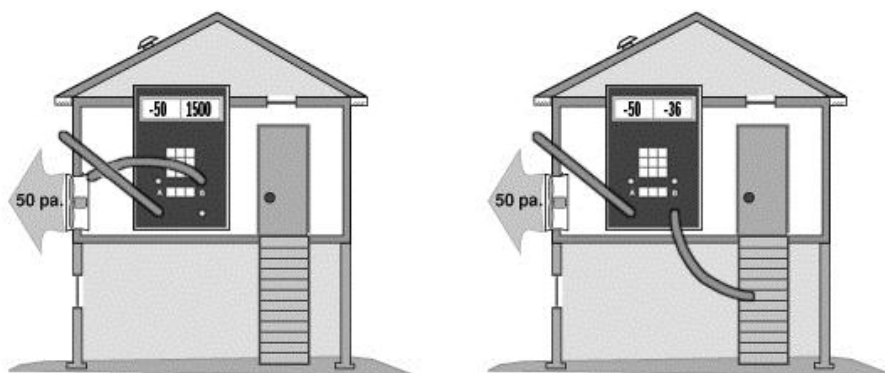
The Open-a-Door method is another way of determining how much leakage in CFM<sub>50</sub> travels through an intermediate zone like a walk-up attic, unoccupied basement, or attached garage. This method requires a door between the house and zone or between the zone and outdoors. Use the Open-a-Door or garage ZPD worksheet within the Diagnostic Workbook to perform the calculations.

The Add-a-Hole worksheet calculates Leakage Results based on user data inputs. The three Leakage Results calculations are:

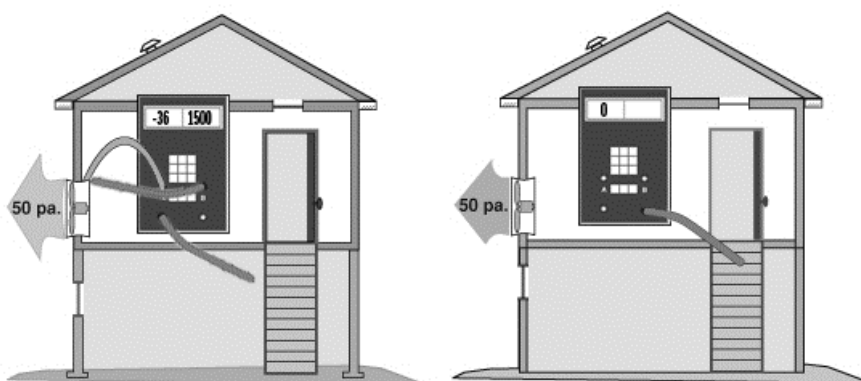
**Total path:** This number represents the amount of CFM<sub>50</sub> passing through both pressure boundaries.

**House with reference to zone:** This number represents the amount of leakage between the house and zone.

**Zone with reference to outside:** This number represents the amount of leakage between the zone and outside.



**Open-a-door test:** Start with a CFM<sub>50</sub> reading and a pressure difference between house and the basement zone.



**Open-a-door test 2:** Now open the door, and read the new CFM<sub>50</sub>, while making sure that there is no pressure difference across the door.



The target air leakage for attached garages is 50 CFM, although ideally the goal should be to have zero leakage between a house and garage. As stated in *Section 1.5*, the target total path leakage percentage for attics is 10 percent or less of the total blower door value.

Follow these steps to complete the Open-a-Door test:

1. Set up for a standard blower door test. Put the home in winter condition, turn off all combustion appliances, and keep interior doors stationary during testing.
2. Run a pressure hose to the outdoors. Run a second pressure hose into the zone, keeping the hose end away from roof vents and large bypasses. Both hoses will be connected to the digital pressure gauge later during the test. Ensure each hose is long enough to reach.
3. Turn on the pressure gauge and leave in PR/PR mode for pressure testing. *Do not use the Adjusted Baseline feature of the digital gauge when completing zone-pressure diagnostics.*
4. Connect a jumper tee to the Channel A Input tap and the Channel B Reference tap. Leave the jumper tap open to the indoors for the time being, with no hose connected. Connect the outdoor pressure hose to the Channel A Reference tap of the digital pressure gauge
5. Open the Open a Door or Garage ZPD worksheet in the Diagnostic Workbook. Select the Type of Test — depressurization or pressurization — to be conducted.
6. Connect the zone pressure hose to the jumper tee. Record the Zone with reference to Outside (ZwrtO) baseline from Channel A, and the House with reference to Zone (HwrtZ) baseline from Channel B.
7. Remove the zone pressure hose. Measure the House with reference to Outdoors (HwrtO) baseline pressure differential. Enter the result in the Diagnostic Workbook, as a positive or a negative number. The Workbook will then calculate the Adjusted Pressure — which is the target pressure reading during the blower door test.
8. Start the blower door fan to create a HwrtO pressure difference and adjust to match the targeted pressure reading.
9. Reconnect the zone pressure hose to the jumper tee. Record the ZwrtO reading from Channel A, in the Pressure with House at 50 Pascals line of the Open a Door or Garage ZPD worksheet. Record the HwrtZ reading from Channel B, in the same line of the worksheet.
10. Complete a blower door test with the door closed and record on the Open a Door or Garage ZPD worksheet.
11. Open the door between the house and the zone or garage. The door to be opened will be between the basement and the outside when determining leakage to the basement from outside.

12. Complete a blower door test with the door open and record on the Open a Door or Garage ZPD worksheet.
13. The test is complete. Return the home to the pre-test conditions — and remember to turn combustion appliances back on.
14. Follow the warning indicators in the open a door or Garage ZPD worksheet, if they appear.

As a rule, the sum of the HwrtZ and ZwrtO pressures is equal to the HwrtO pressure. For example, if the HwrtZ pressure is -45 Pascals and the ZwrtO pressure is -6 Pa, then the HwrtO will calculate out to -51 Pascals ( $-45 + -6 = -51$ ). The greater the difference between the HwrtO and the sum of the HwrtZ + ZwrtO pressures, the less accurate the test will be. If the sum goes above 52 Pascals or below 48 Pa, the Add-a-Hole worksheet will instruct diagnosticians to consider re-testing.

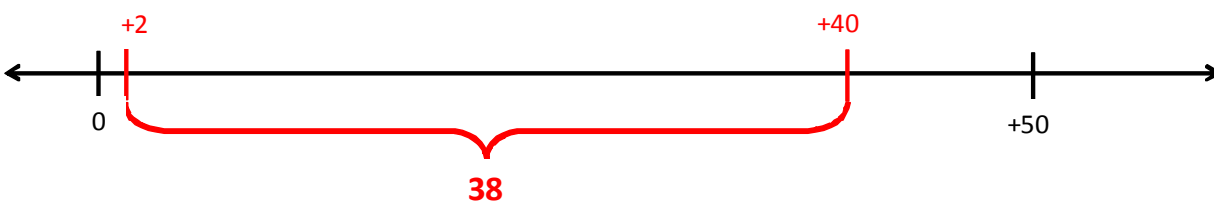
### 1.5.6 Adjusting Zone Pressure Measurements for Baseline

The measured zone pressure baseline readings are subtracted from the measure zone pressure readings taken with the house at a 50 Pascal pressure difference. This can be confusing when subtracting a negative number from a negative reading (depressurization) or a positive reading (pressurization). The number lines below are examples on how to adjust for baseline for both pressurization and depressurization testing methods. (The Diagnostic Workbook will make this adjustment automatically.)

#### Pressurization

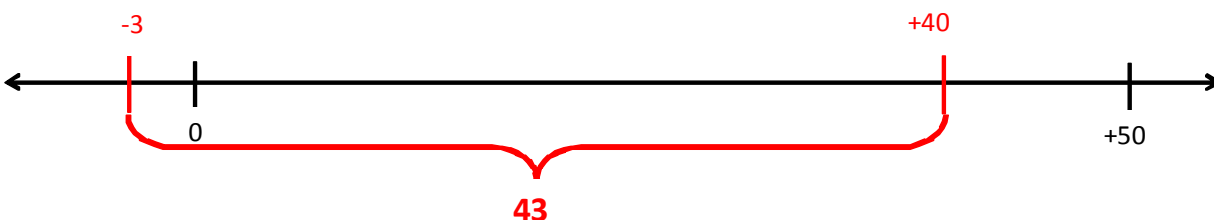
Positive baseline of +2, zone reading of 40 with house at 50.

Adjusted zone pressure reading is 38 ( $40 - (+2) = 38$ ).



Negative baseline of -3, zone reading of 40 with house at 50.

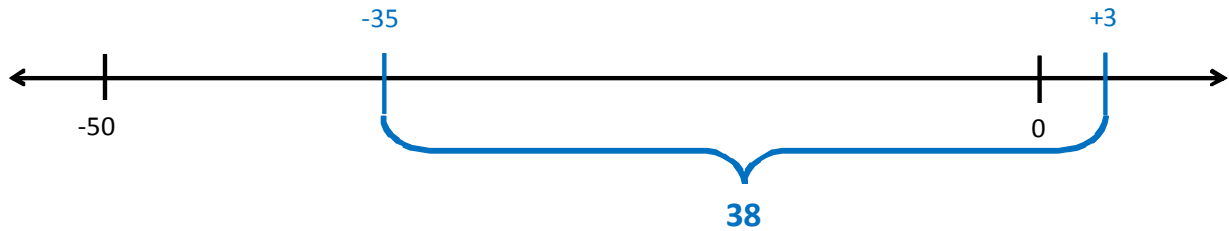
Adjusted zone pressure reading is 43 ( $40 - (-3) = 43$ ).



### Depressurization

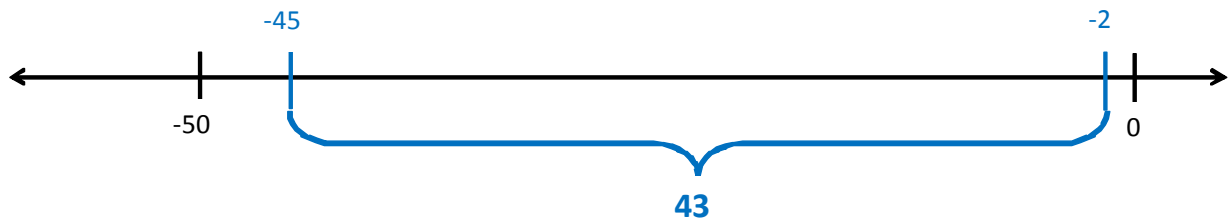
Positive baseline of +3, zone reading of -35 with house at -50.

Adjusted zone pressure reading is 38 ( $-35 - (-3) = -38$ ).



Negative baseline of -2, zone reading of -45 with house at -50.

Adjusted zone pressure reading is 43 ( $-45 - (-2) = -43$ )



## **Final Inspection and Quality Assurance Standards**

Acceptable installations for air sealing measures and diagnostic testing should reflect the following.

### **Air Sealing and Building Diagnostics**

#### **General**

1. The customer file contains documentation of all diagnostic, air-sealing, and combustion-safety testing that was performed at the building.
2. Diagnostic tests were appropriate for the building's configuration.
3. Program guidelines were followed in reducing air leakage (e.g., WCEG, ZPD, and one-hour maximum for comfort sealing).

#### **Air Sealing**

1. All major attic bypasses and building key junctures are sealed.
2. All major bypasses and gross holes in the box-sill are air sealed.
3. Broken or missing windows have been patched, repaired, or replaced.
4. The air sealing hours and testing are documented on the Blower Door Tests and Sealing Summary form.
5. Air sealing materials perform the intended function.
6. If caulk is applied in a paintable situation, then paintable caulk was used.
7. If used, foam sealant was applied judiciously.
8. Weather-stripping is installed only on exterior doors, not on interior doors.

#### **Blower Door Test**

1. The equipment was calibrated within the last year.
2. The final blower door value can be replicated +/- 20%. (Final Inspection, QA Inspection).
3. The Blower Door Tests and Sealing Summary form is complete.

#### **Zone Pressure Diagnostics**

1. Where required, ZPD testing was performed and is properly documented in the file or Diagnostic Workbook.
2. The appropriate method was used when testing was completed (e.g., open-a-door, add-a-hole).